Stratified Coastal Trapped Waves and Mean Flows

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LONG-TERM GOALS

Our long term goals are to identify the roles that rectified subinertial waves and mesoscale motions play in the mean-flow transport of fluid properties in the coastal ocean and to apply these ideas to cross-margin transport of physical, chemical, and biological properties. In addition, we are interested in the interaction and relative effect of wave-driven transport versus frictionally driven boundary layer transport.

OBJECTIVES

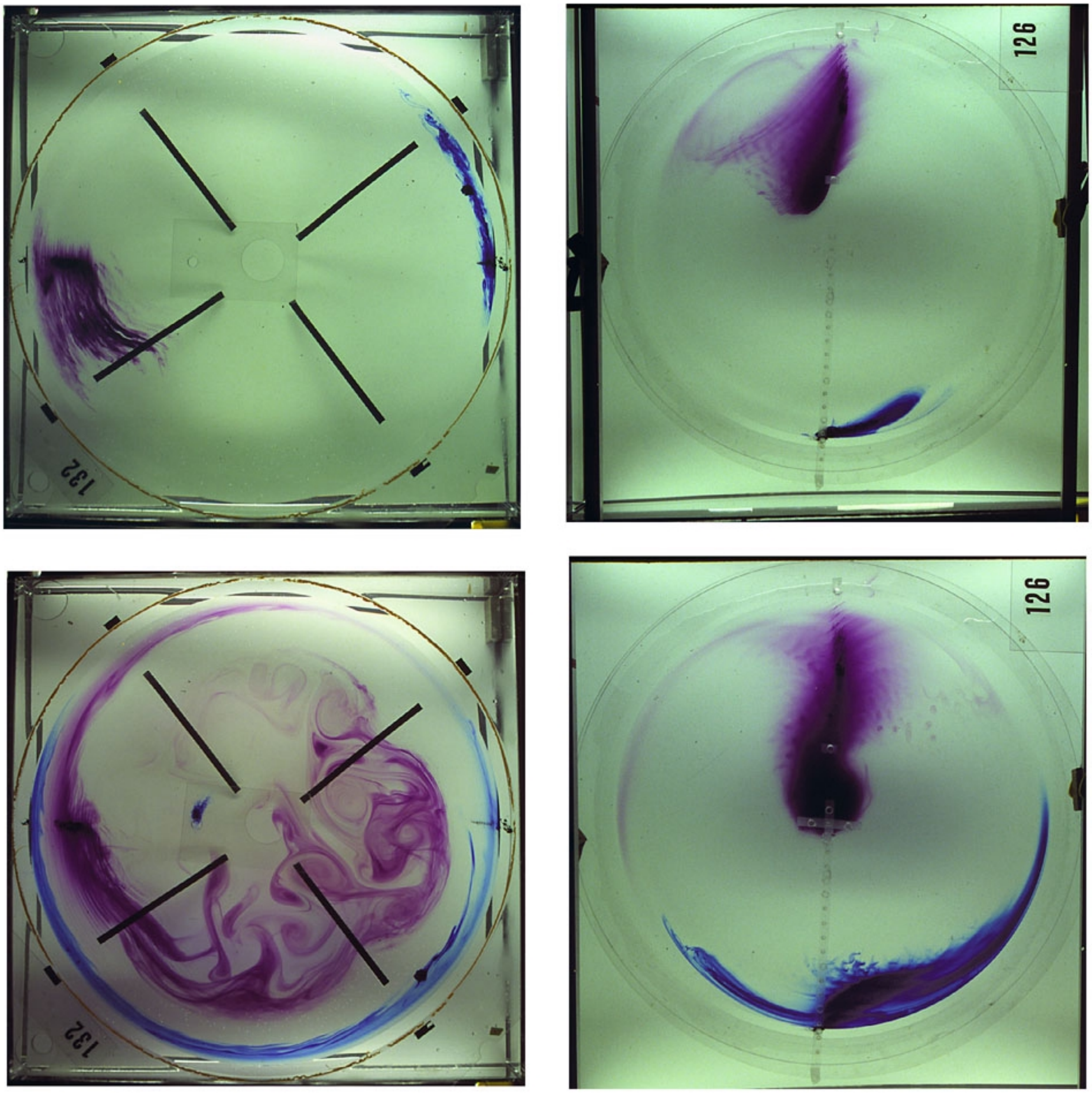
Coastal waves and wave-generated mean flows are studied in a stratified, rotating model ocean. Waves trapped to the coast are generated by time-dependent flow over a sloping and irregular bottom. We study flow resulting from oscillatory flow over a sloping bottom, both with and without stratification, and with and without additional topographic features. Short-term goals of this study include quantifying the vertical structure of the along-slope mean flow driven by non-linear interactions of the coastal trapped wave and asymmetries in Ekman layer development. The effects of stratification on the cross-slope overturning circulation will be examined to evaluate the strength of wave-driven mean flow verses frictionally driven flow.

APPROACH

The approach for this research was to use laboratory experiments and two types of numerical models. The laboratory experiments are fully non-linear by their very nature, while the numerical models provide a useful venue for studying specific processes and offer much better diagnostics.

The approach that we take here is to build do a series of laboratory experiments each with additional physical complications. In the laboratory experiments, we do experiments both with a bowl-shaped tank, and with a bowl shaped tanked with four radial ridges to generate standing wave. Numerical experiments were be done in parallel to simulate the stratified problem to be able to diagnose the causes of any rectified circulation observed.

In addition to the isopycnal numerical model that is used to simulate the laboratory experiment, work is completed on a semi-analytical study of wave-mean flow itneractions of topographic Rossby waves that are the quasi-geostrophic equivalent of coastally trapped waves. Work is nearly complete testing a new formulation of the overturning circulation in a stratified fluid where topographic slope is large, such as on the continental slope.



1. Tracer distributions from the laboratory experiment. Upper right hand corner shows the initial release point of the tracers for the homogeneous experiments in a smooth bowl. Below that show the tracers some time later. The tracers are advected cyclonically throughout the fluid. The upper left hand corner shows the release points of the tracers for the stratified experiment with ridges on the bowl. Below that shows that the tracers are advected anitcyclonically near the rim, and cyclonically in the interior.

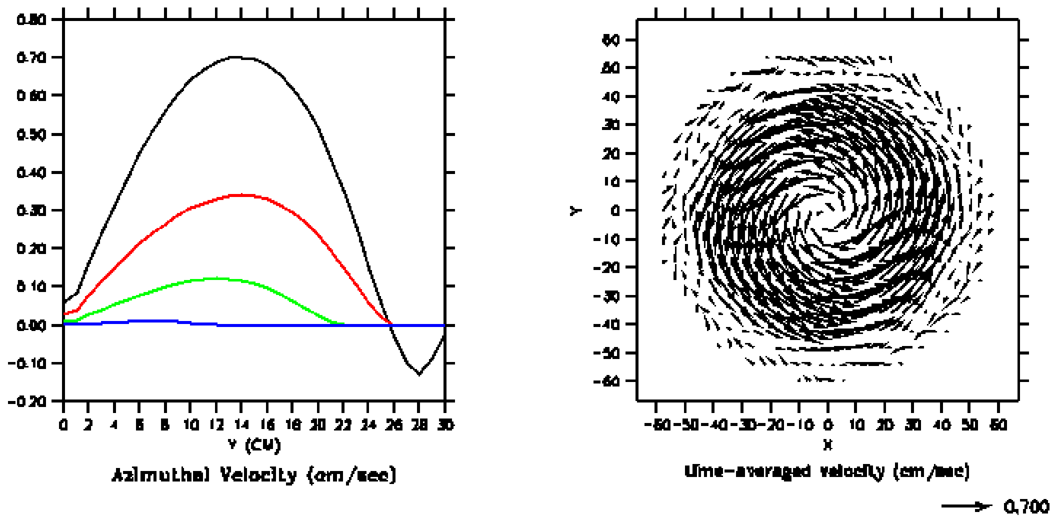
WORK COMPLETED

With the help of Dr. Peter Rhines, we brought Dr. Boris Boubnov to the University of Washington to complete the laboratory experiments. In the space of two months, Dr. Boubnov performed over 130 experiments. With various visualization techniques, we have shown two distinct flow regimes, depending on whether the flow is homogeneous or stratified. Parallel numerical experiments were done and diagnostics were done on the model. Two analytical models were developed to provide a simpler framework with which to explain understand the laboratory results. A new formulation for the residual circulation (the cross-slope circulation of mass for the quasi-linear wave-mean flow interaction problem) has been developed applied to output from the Brink and Chapman model.

Unfortunately, Dr. Boubnov passed away this summer, so that the completion of the paper describing the laboratory work has been delayed. With Dr. Rhines, we expect that a paper will be completed this fall.

RESULTS

Results form the laboratory experiments shows that in homogeneous fluid, in the absence of topographic ridges, there is net mean flow in the cyclonic direction, in the direction that Kelvin waves and coastal trapped waves travel (Figure 1). A similar flow can be seen in the numerical experiments (Figure 2). In contrast, when the fluid is stratified and there are no ridges, the flow is anticylonic. This results from fundamental differences with the boundary layer structure when the flow is stratified and there is a sloping bottom. Using the ideas of MacCready and Rhines (19) a simple analytical solution was derived and it was shown that for laboratory scaling, the resulting mean flow would be on the order of the oscillatory flow. The laboratory parameters allow a scale separation between the spin down time for cyclonic flow and anticyclonic flow. However, when ridges are included in either the homogeneous or stratified experiments, the resulting flow is for the most part cyclonic. There is a small band of anticyclonic flow at the outer rim of the bowl in the stratified experiments. Numerical experiments using laboratory scaling show similar results both in the stratified and unstratified cases. The resulting azimuthal and temporal mean flow shows that the flow is largest near the surface and is maximum about half way into the tank. In the numerical model, the mass-flux can be calculated. The resulting mass flux is consistent with mean flow generation and the resulting modification of the density field and thermal wind. There is a flux of mass towards the center of the bowl near the bottom, with a more diffuse return flow throughout the rest of the fluid (Figure 3).

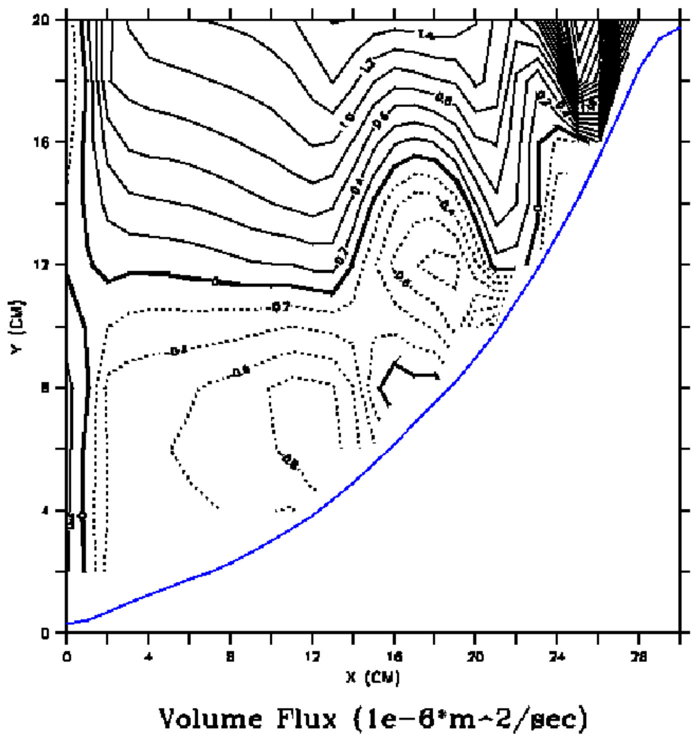


2. Left panel shows mean flow that is generated in the numerical model with stratification and ridges as a function of radial distance for each of 4 layers. Note the predominantly cyclonic flow, and the reversed flow near the rim. Right panel shows a plan view of the upper layer flow.

The implications of this work is that mean flow and mass flux associated with wave-driven and boundary layer driven processes are comparable. In fact, neither can be ignored using the laboratory scaling. While the consideration of transport processes associated with boundary layer flow is commonly consider in coastal oceanography modeling, wave-driven processes should also be considered.

Application of some of these ideas is made to the system of mean-flow generated by topographic Rossby waves (Thompson and Evans, 1999). In this work, it is shown that flow reversals can occur even in the absence of boundary layer effects. Also, the formulation of the mean-flow generation problem must be done carefully to gain a consistent scaling of non-linear effects, frictional effects and topographic influences.

The new formulation for the residual circulation (the cross-slope circulation of mass in the quasi-linear problem of wave-mean flow interaction) shows that there are significant differences between a formulation that does not allow transport into the bottom, and the more traditional formulation that does not allow transport through the surface. A paper is in preparation on this work. The Brink and Chapman model has been modified to allow for the calculations of second order quantities and correlations.



3. Mass flux calculated in the numerical model. Note the mass flux towards the center of the bowl near the bottom, and the more diffuse return flow near the surface. Note also the strong positive mass flux near the rim, associated with the flow reversal.

IMPACTS/APPLICATIONS

The results of this study suggest that Ekman shut down effects need to be revisted in the coastal environment. In addition, wave-driven mass flux should also be considered when trying to understand the net cross-shore transport of fluid parcels. This study gives a framework with which to consider how fluid parcels are transported across the shelf and slope.

PUBLICATIONS

Thompson, L. and F. Evans, Topographic Rossby-wave mean flow interaction submitted to *Journal of Physical Oceanography*.